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Long-lasting income shocks and adaptations: Evidence from coral bleaching in Indonesia☆

Pasita Chaijaroen [a,b,c,*]

[a] Vidyasirimedhi Institute of Science and Technology, Rayong, Thailand
[b] College of William & Mary, Williamsburg, VA, USA
[c] University of Washington, Seattle, WA, USA

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ABSTRACT

This paper explores how people adapt to climate shocks, specifically coral bleaching, that have long-lasting impacts on income. Caused mainly by abnormally high sea surface temperature, coral bleaching has significant effects on marine resources. Using panel data from Indonesia and exogenous variations in bleaching, I observe that fishery households in affected areas experienced a decrease in income relative to other households. Although consumption expenditures did not decline significantly in response to these income shocks, these households reduced their protein consumption in the short and long runs. Regarding labor market outcomes, the affected households tended to substantially increase their labor supply and switch industries only in the long run.

1. Introduction

Climate change and its long-term impacts on agriculture have been widely discussed.[1] Also important but much less studied are the potential negative impacts of rising ocean temperatures and other marine changes. For example, massive coral bleaching events weaken coral reefs around the world and adversely affect fish species higher up in the food chain. Ocean acidification also hampers shell formation in crustaceans. Given that 61% of the world's GNP comes from coastal areas[2] and 16.7% of global animal protein consumption is derived from fish (FAO, 2014), these impacts could be substantial.

This paper explores the relationship between climate change, income shocks, and adaptation mechanisms within marine industries. I investigate the changes in labor market outcomes and consumption as households experience negative income shocks due to coral bleaching. Coral bleaching is a natural phenomenon where coral reefs are weakened due to abnormally high sea surface temperature (SST). Coral reefs are a habitat and food source for a vast number of species; thus, fishing households that are strongly tied to the ocean can be adversely affected by coral bleaching. Furthermore, because marine resources take extended time to recover, these shocks can persist for many years.

The empirical analysis in this paper is based on the Indonesian fishery sector using the Indonesian Family Life Survey (IFLS). Identification relies on the premise that coral bleaching is exogenous to household behavior. Subsequently, since massive coral bleaching in 1998 was mainly induced by El Niño, it satisfies the identification assumption. With reported bleaching spots in some of the IFLS provinces, the

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* 555 Moo 1, Payupnai, Wangchan, Rayong 21210, Thailand.
E-mail address: pasita.c@gmail.com.

[1] For instance, Schlenker et al. (2006) observed a large negative impact of climate change on U.S. farm land values using a hedonic approach, and Deschênes and Greenstone (2012) found that the effect of climate change on U.S. agricultural profit can range from negative to statistically insignificant. Dell et al. (2014) comprehensively discuss this literature.

[2] Coastal areas are defined as those within 100 km of the coastline (UNEP, 2006).

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identification strategy compares fishery households that lived in coral bleaching areas to both nonfishery households in the same areas and other fishery households outside of the coral bleaching zones. To mitigate a concern on measurement errors, I also use an SST measure based on remote sensing data as a proxy for coral bleaching. I then explore how the treatment effects vary over the years after coral bleaching because adjustments can be different over time.

Three main results emerge. First, fishing households in the coral bleaching areas in 1998 experienced a significant drop in income two years after but not nine years later as observed in the 2000 and 2007 surveys. Second, most labor-related adjustments happened in 2007. The affected households were more likely to switch to a new industry and increase their labor supply. They were also more likely to migrate, but some evidence suggests that migration could have occurred earlier in 2000. Third, consistent with the literature on income elasticity of food consumption,[3] strong evidence suggests a decrease in protein consumption in 2000, and some evidence indicates that this consumption shock is persistent.

This paper is related to two main strands of literature. The first is the large body of work on the impacts of climate change on humans. Most of the economic literature related to climate change has dealt with the U.S. agricultural sector. A number of papers find negative impacts from an increase in temperature on agricultural land values and agricultural profits in the U.S. (e.g. Schlenker et al., 2006; Deschênes and Greenstone, 2012). In addition to weather patterns, climate change could bring about more frequent and severe extreme weather events and natural disasters, which can wipe out resources and lead to tremendous economic losses (e.g. Hsiang and Jina, 2014).

The impacts of climate change tend to be large in developing countries due to the severity of climate change in these areas and the lack of adequate safety nets and risk sharing mechanisms in these countries. Nonetheless, literature on climate change in the developing world is relatively small. A few studies have suggested that climate change is expected to decrease crop yields (Guiteras, 2009; Schlenker and Lobell, 2010). Indian households mitigate these shocks by changing crop mix and investing in irrigation as well as shifting the labor supply to manufacturing. The technological adjustments within the agricultural sector result in a small loss recovery (Taraz, 2017), while labor reallocation to manufacturing substantially alleviates the adverse economic consequences (Colmer, 2016).

This paper demonstrates that the adverse impacts of climate change are not limited to the agricultural sector. The fishery sector could also experience an income loss as the temperature rises. Furthermore, climate change might impose risks on nutrition intake, especially in vulnerable communities in developing countries. Although coral bleaching might be considered a one-off shock similar to other natural disasters in this literature, its direct effects are more likely to be limited to some industries and might be easier to mitigate. Consistent with the findings in Taraz (2017), adjustments after climate change featured in this paper happened mostly in the long run. Similar to the labor reallocation results in Colmer (2016), I also find evidence of industry switching, but the switching occurs much later than what Colmer (2016) finds.

In addition to the climate change literature, this paper contributes to the substantial amount of literature on income shocks. Most income shocks in the economic literature are either relatively short-term shocks, such as a crop loss from a temporary change in rainfall pattern (e.g. Wolpin, 1982; Paxson, 1993), or expected long-term shocks, such as the birth of a girl and her associated future dowry payment (Deolalikar and Rose, 1998). This paper offers a unique opportunity to investigate how economic agents mitigate income shocks that are both long-lasting and unexpected.

As climate change continues, unexpected, large, and long-lasting shocks will be more common. Understanding how people react to these events is crucial because their effects on economic agents may be larger than those from short-term or anticipated shocks. In the literature, savings and risk sharing mechanisms allow households to smooth consumption after a crop loss (e.g. Paxson, 1993; Townsend, 1994). Agricultural households also respond to losses in crop income by increasing labor supply and labor force participation (Kochar, 1999; Rose, 2001). Adjustment mechanisms in this paper are largely similar to those in this literature, with the exception that most adaptations considered here happened years after the shock rather than months after. This delay might be because income shocks from climate change are difficult to mitigate.

The rest of the paper is organized as follows. Section 2 provides details on coral bleaching and the fishery sector in Indonesia. Section 3 outlines a theoretical framework for fishery, consumption, labor supply, and migration. Section 4 discusses the empirical framework, including data and identification. Section 5 presents the empirical results. Section 6 suggests policy implications and concludes.

2. Background on coral bleaching and fishery in Indonesia

Coral bleaching is a natural phenomenon by which coral reefs lose their colors mainly because of abnormally high SST. As SST rises, corals expel the symbiotic algae on which they feed (Brown, 1997). Corals usually regain their colors in a few months if they survive the bleaching process. However, if the temperature remains high for a long period of time, corals usually die (Wilkinson and Hodgson, 1999; Hoegh-Guldberg, 1999). In that case, it takes many years for the reef to recover. New coral larvae or polyps must settle into the old reef structure and regrow, and the rate of growth ranges between less than 1 inch to 4 inches per year, depending on the species (NOAA, 2015).

Over the past few decades, massive coral bleaching events were reported in 1998, 2010, and 2014–16. As the impact of coral bleaching can be long term, I focus on the earliest of these events. The coral bleaching in 1998 occurred as a result of the severe El Niño from 1997 to 98. The SST anomaly spanned from the eastern coast of Africa to as far as Japan and Australia during the first half of 1998. This temperature increase resulted in a number of reported bleaching spots in the Indian and the Pacific Oceans (Goreau et al., 2000). In Indonesia, bleaching spots were reported in West Sumatra, the south shore of Central Java, Bali and Lombok area, and Southern Sulawesi. Coral mortality rates in the Indian Ocean ranged from 70% to 99%; in the Bali area, mortality was estimated at approximately 50% (Goreau et al., 2000).

Coral mortality has a devastating effect on fish that depend on corals for food, habitat, and recruitment (Pratchett et al., 2008). Scientific studies find the degree to which coral bleaching impacts fish stock varies depending on species and location.[4] In general, coral depletion leads to a rapid decline in the abundance of coral reef species in the short to medium term (up to three years after coral bleaching). In the long term, if corals fail to recover, fish composition will change, and the overall abundance and diversity will decline (van Oppen and Lough, 2008). The literature has suggested that damaged corals require at least five years to recover, provided the reef is not permanently

[3] For example, Subramanian and Deaton (1996) estimate the elasticity of calorie consumption with respect to total expenditure in India to be approximately 0.3–0.5, suggesting that calorie intake is a normal good. In the context of Indonesia, Skoufias et al. (2012) estimate the similar elasticity to range from 0.12 to 0.25. In addition, they find that the income elasticity of starchy staple to total calorie ratio ranges from −0.21–−0.31 implying that households consume less starchy staples as their income increases.

[4] For example, Garpe et al. (2006) observed that total abundance and taxonomic richness of species increased immediately after coral bleaching in Tanzania, but both measures significantly declined below the initial level of six years after the bleaching. Booth and Beretta (2002) found a lower recruitment of fish at bleached southern Great Barrier Reef sites relative to unbleached sites one year after the bleaching.

ruined (e.g. Graham et al., 2007; Wilkinson and Hodgson, 1999).[5]

Coral bleaching can affect humans in a couple of ways. In this paper, I focus on implications for the fishery sector, where reduction in the abundance and diversity of fish potentially affects fishing efforts, yields, and income. Coral bleaching is expected to have large impacts on small-scale fishery because small boats cannot travel to distant, unaffected areas. Most of the Indonesian fishery sector is considered small or medium scale, characterized by nonpower or outboard-engine boats. In the coral bleaching areas of Indonesia, more than half of fishing boats are nonpower and outboard-engine. Notably, the majority of fishing boats in these areas were non-power in 2000 except for Central Java and Bali, where outboard-engines predominate. In Bali, where most of the fishery households in the IFLS live, approximately 40% of fishing boats were nonpower and less than 5% were inboard-engine (Statistics Indonesia, 2015).

3. Theoretical framework for consumption, labor supply, and migration

In this section, I propose a theoretical framework to demonstrate how consumption and labor activities change after an exogenous shock to a fish stock resource. The model is based on the agricultural household framework but applied to a household that engages in fishery production and consumption.

The household maximizes its utility, $u(FC_t, C_t)$, where FC_t represents fish consumed and C_t represents non-fish consumption, subject to a budget constraint. Fishery production requires two inputs: a fish stock resource and labor, $F_t(\theta, LF_t)$. The initial fish endowment, θ, is given and exogenous. The household may supply labor outside of fisheries, LW_t, and migrate, M_t, to increase wages received from non-fishery jobs.

To illustrate that adaptations in the short and long runs can be different, the model contains two periods: immediately after the shock and the long run. The key difference between the two periods is the marginal benefit of migration. Migration in the first period improves wages in both periods, but migration in the second period affects only the second period wage.

I consider two scenarios for fish prices. I first assume that the fish prices are exogenous and that they grow at the same rate as the other prices in the model. In this scenario, the model suggests that a decrease in an initial resource condition leads to declines in household income, fish consumption, non-fish consumption, fish consumption expenditure, non-fish consumption expenditure and fishery labor input, and an increase in migration. Since migration in the first period allows the household to enjoy higher wages sooner, the increase in migration in the first period is greater than that in the second period.

In the second scenario, the market for fish is perfectly competitive, and fish prices adjust so that the market clears in each period. In this scenario, only fish consumption decreases after a shock to the fish resource. The shock results in higher fish prices, so the household does not change migration or fishery labor input in response to the shock. In addition, neither fish consumption expenditure nor total consumption expenditure changes in either periods. Further details on the theoretical framework are discussed in Appendix A.

4. Empirical framework

4.1. Data

The main sources of data in this paper are the IFLS,[6] reported coral bleaching spots from Goreau et al. (2000), and SST anomalies from the National Oceanic and Atmospheric Administration (NOAA) satellite maps. The IFLS is a panel that has been tracking 7224 Indonesian households since 1993. The survey includes detailed information on socioeconomic status, consumption, labor market history, and migration. Currently, the IFLS is available for 1993, 1997, 2000, 2007, and 2014. This paper will utilize the first four waves of data.

In explorations of labor-related outcomes, especially migration, attrition might be a concern. However, the IFLS's overall attrition rate is relatively low,[7] compared with other panel datasets in developing countries. A simple test[8] indicates that attrition is not significantly different between the treated and control groups.

The IFLS is then combined with the data on coral bleaching. The first source of coral bleaching data are reported coral bleaching spots from Goreau et al. (2000). This paper gathers reef data primarily from long-term observers who documented the state of the reefs before and after coral bleaching. This comparison guarantees that the damage reported was caused by coral bleaching rather than other factors that might have damaged the corals beforehand. Nonetheless, as with other reported data, the reported coral bleaching spots may not be comprehensive because some areas may not have been reported. To show that this problem is not a concern, I also use the number of days with SST anomaly based on remote sensing maps as a proxy for coral bleaching and demonstrate that the results are similar under both specifications.

A popular model for coral bleaching prediction (Hoegh-Guldberg, 1999) postulates that coral bleaching is likely to occur when SST is more than 1°C above the normal summer average for at least three to four weeks. NOAA has been using this SST anomaly measure to predict coral bleaching since the 1990s and has been successful in predicting massive bleaching events (Hoegh-Guldberg, 1999). In this paper, the number of days with an SST anomaly is constructed from NOAA satellite images available every one to seven days for the first half of 1998. For each coastal area, defined as one ocean coastline in one province,[9] I calculate days with SST anomalies based on the maps from January to June 1998, the period during which we know SST anomalies have occurred. This SST anomaly days measure is then merged with household data at a coastal area level.

4.2. Methodology

The goal of this empirical study is to identify how households adapt after a shock with coral bleaching serving as a natural experiment. A decrease in income caused by coral bleaching should be exogenous for two reasons. First, households do not directly cause coral bleaching. The 1998 coral bleaching in Indonesia was mainly induced by El Niño, a natural shift in weather patterns in the Pacific. Second, these households were unlikely to anticipate coral bleaching because even scientists predicted the 1998 coral bleaching only days in advance (Hoegh-Guldberg, 1999).

[5] The evidence is sparse because the 1998 coral bleaching was the first to be widely documented; thus, data for the pre-bleaching period were limited. One of the few studies, Graham et al. (2007), studied the long-term impact of the 1998 coral bleaching in Seychelles. They observed that coral reefs did not fully recover by 2005, and fish reproduction was minimal. A follow-up study in the same area in 2011 indicates that 11 out of 21 reef sites recovered and 9 sites were permanently ruined and replaced by algae (Graham et al., 2015).

[6] Frankenberg and Karoly (1995), Frankenberg and Duncan (2000), Strauss et al. (2004), and Strauss et al. (2009).

[7] Among fishery households, the re-contact rate among the original 1993 households in 2007 was 95.83%. This re-contact rate was 93.6% among all original IFLS households.

[8] A test where a dummy indicator for failure to contact a household was regressed on all regressors appeared in the main estimating equation.

[9] The exception to this rule is Bali and West Nusa Tengara where the two provinces are treated as one coastal area. This is due to the small-island nature of these provinces and the fact that SST anomaly was similar in the whole area.

Table 1
Differences between coral bleaching and other areas *ex ante*.

Variable	Mean	Single diff	P value	Double diff	P value	N
HH head's age	46.78	0.785	0.477	0.646	0.539	13,892
Male HH head	0.828	−0.018	0.474	0.016	0.205	13,892
Income	13.37	−0.179	0.217	−0.106	0.248	10,001
Migration	0.188	−0.005	0.843	NA	NA	7516
Working hours per week	28.37	1.426	0.380	1.107	0.517	14,595
Working weeks per year	30.17	4.528	0.086	2.745	0.245	14,620
Second jobs	0.259	0.114	0.014	0.110	0.124	14,658
HH members in fisheries	0.030	0.013	0.643	0.004	0.465	13,939
Nonfood expdt	10.65	0.010	0.952	−0.167	0.195	14,155
Total food expdt	8.704	−0.048	0.660	−0.073	0.181	14,563
Protein expdt	6.509	0.011	0.962	−0.098	0.648	14,563

Remarks: Averages are calculated from all households in the 1993 and 1997 waves. Column 3 shows single differences in means between areas with and without coral bleaching using all households from the 1993 and 1997 waves ($\overline{x}_{bleached} - \overline{x}_{unbleached}$). Column 5 contains double differences from 1993 to 1997 waves. P values are based on province clustered standard errors. Income is log of real household income per worker. Migration is a dummy variable equal to 1 if the household moved from their location in the previous wave. Working hours and working weeks are per worker year. Second jobs is the total number of second jobs among all household members. All consumption variables are log of consumption expenditure per household member.

The empirical modeling involves identifying an impact of coral bleaching on income and investigating an aftermath of the income shock. The main estimating equation is a difference-in-differences (DiD) specification with time-varying treatment effects as the theoretical framework suggests that the effects can be different between the short and long runs.

The DiD design involves two pretreatment waves of data and another two waves post-treatment. The first four waves of the IFLS are 1993, 1997, 2000, and 2007. As coral bleaching occurred in 1998, the 1993 and 1997 waves of data are the pretreatment period. The 2000 wave serves as a short-run post-treatment period, and the 2007 wave represents the long run.

Treated households are defined as those engaged in fishery and living in the affected areas in 1997. The affected (treated) area includes provinces with reported bleaching spots in Goreau et al. (2000), namely, Bali, West Nusa Tenggara, West Sumatra, the Indian Ocean coastal areas of Central Java, Yogyakarta, and South Sulawesi (see Fig. B.1). Of the 7516 households surveyed in 1997, 2191 households lived in the areas with reported coral bleaching spots, and 196 engaged in fishing. Among these households, 76 both fished and lived in the coral bleaching area and constituted the treated group. This treatment status is held constant across all waves of data.

Based on this binary treatment specification, there are two possible control groups: nonfishery households in coral bleaching areas, and fishery households outside of the coral bleaching areas. Using the geographical control group makes intuitive sense because people in the same location experience similar shocks and changes. For example, households in a particular area usually face similar prices and weather-related shocks. Using fishery households in other areas as a control group is motivated by the dramatic changes in macroeconomic factors during the period of study. The Asian Financial Crisis started in 1997 and resulted in a significant depreciation of the rupiah. The fishery sector responded to this macroeconomic change by shifting to fishing for live fish for exports instead of for domestic consumption. Moreover, aggressive fishing methods were used more widely than before. Using the fishery control group helps account for these fishery-specific unobservables.

Let Y_{ht} be a dependent variable of interest. The estimating equation when using a binary treatment definition can then be written as

$$Y_{ht} = \alpha + \delta_1 Treat_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave=\tau)*Treat_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (1)$$

where h is a subscript for household and t is a subscript for time. $I(wave = \tau)$ is an indicator function for each wave of the post-treatment period, $Treat_h$ is the treatment status, and X_{ht} is a vector of control covariates. The model also contains household fixed effects, μ_h, and wave fixed effects, λ_t. Control covariates include a set of dummy variables for the provinces of residence and characteristics of household heads, such as age and education. As a result, the model accounts for predetermined factors constant within households, any particular wave, and provinces of residence.

Similar to (1), the estimating equation under the SST anomaly days specification takes the form

$$Y_{ht} = \alpha + \delta_1 SSTdays_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave=\tau)*SSTdays_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (2)$$

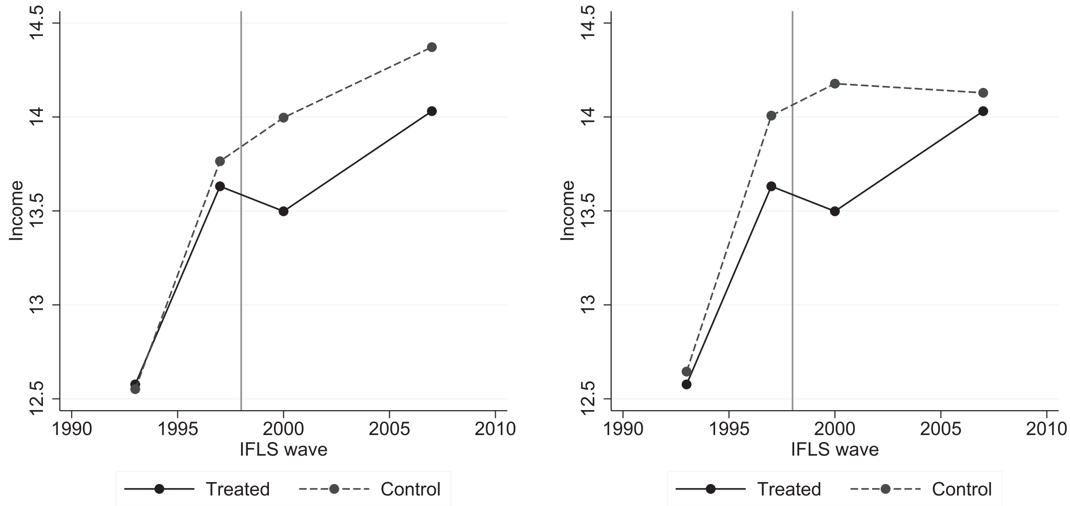
where $SSTdays_h$ denotes the number of SST anomaly days household h faced during the 1998 coral bleaching.

The treatment using the SST anomaly days is defined based on both the actual SST anomaly days for each coastal area and the household's occupation. In particular, SST anomaly days equals zero for all nonfishery households and is equal to the actual SST anomaly days for all fishery households. SST anomaly days can be greater than zero for fishery households that lived outside of coral bleaching areas. The binary treatment variable based on reported coral bleaching and this SST measure are positively correlated, but the correlation is not perfect.[10]

The regression samples for the SST anomaly days models mimic those under the binary treatment specifications. In particular, one regression sample includes all fishery households regardless of where they lived, and another sample contains all households in areas with reported coral bleaching.

The key identification assumption is that coral bleaching is exogenous. I first checked this assumption by investigating if areas with and without coral bleaching differed in terms of socioeconomic characteristics *ex ante*. Column 3 in Table 1 shows single differences in means of key variables between bleached and unbleached areas using the first two waves of data. Most of these differences are not statistically significant suggesting coral bleaching was mostly random with respect to the preexisting socioeconomic characteristics. I also examined if the preexisting differences changed over time. The double differences in column 5 are not statistically significant implying that households were unlikely to anticipate and act on the shock *ex ante*, at least at the aggregate level.

[10] Most of the control area has zero SST anomaly days, and its SST exposure is very small when it is nonzero. Figure B.2 compares the empirical distributions of SST anomaly days between the treated and the fishery control groups.



(a) Within coral bleaching areas (b) Among fishery households

Note: Averages are calculated from the households with positive income.

Fig. 1. Average income over time for the treated and control groups.

In addition, I checked if the treated and control groups were different *ex ante*. The summary statistics based on the 1997 wave of data (Table B.1) indicate that the treated households work harder on average than both control groups. Moreover, some of the treated group's consumption expenditures are smaller relative to the control groups. The differences between the treated and control groups prior to coral bleaching are not an identification concern as long as the three groups have similar trends in dependent variables before the treatment. For example, the Asian Crisis, which started in 1997, must have affected the treatment and control groups in the same manner. Fig. 1 helps validate this assumption by comparing the treated and the control groups' trends of log of real household income over time.[11] The log of real household income is similar among the three groups prior to the 2000 wave. After the coral bleaching in 1998, the treatment group's income decreased in 2000 before increasing in 2007.[12]

The second empirical consideration is measurement errors. My measures of coral bleaching may contain varying extents of measurement errors. The binary treatment based on reported bleaching spots could suffer from underreporting. The second measure, the number of days with SST anomalies, is more continuous and does not suffer from underreporting. However, it may not perfectly predict the actual bleaching events. The SST threshold can vary by location and coral species (Hughes et al., 2003). In addition, even though the SST anomaly is the most important cause of massive coral bleaching, other factors, such as depth of water and water salinity, could also adversely affect the coral reefs. In either case, the classic measurement error biases the OLS estimates toward zero. Despite the possible measurement errors, I find significant impacts of coral bleaching on various outcomes using both measures of coral bleaching and both definitions of control groups.

5. Empirical results

Using the proposed empirical models, I first investigate whether coral bleaching is associated with a reduction in income among the affected households relative to other households. Then, I explore how the affected households adjust their labor market decisions and consumption.

5.1. Income shock

Across various specifications, empirical results suggest that coral bleaching was associated with a relatively large income shock among the affected fishery households in 2000, two years after coral bleaching. The income shock in 2000 was mitigated overtime; thus, the income in 2007, nine years after coral bleaching, was at a level comparable with the control groups. This finding is consistent with a theoretical finding that household income decreases after a shock to the initial fish resource condition, and the income shock is larger in the short run than in the long run.

Table 2 demonstrates the effects of coral bleaching on income based on equations (1) and (2). The key dependent variable is log of real household income per worker. Columns 1 and 3 in Table 2 present the treatment coefficients using the geographical and fishery control groups, respectively. The coefficients on an interaction term $I(2000) * treat_h$ are negative and large in magnitude under both control group specifications. Using the geographic control group, the coefficient on $I(2000) * Fish_h$ is estimated to be −0.3236. This implies that the treated group's income decreased 27% relative to the average income of nonfishery households in the same area. The coefficient on $I(2000) * Bleach_h$ using the fishery control group is −0.6213, which translates to a 46.3% average decline in income among the treated group relative to other fishery households. This finding is also confirmed under the SST anomaly specifications—the coefficients on $I(2000) * SSTdays_h$ are also negative and translated to a 29.6% decline in income relative to the geographical control group, and a 38.1% decline in income relative to the fishery control group.[13] By contrast, the coefficients for 2007 are not statistically significant in any specifications. Tests with a null hypothesis $H_0: \beta_{2000} = \beta_{2007}$ also suggest that income changed from 2000 to

[11] Similar graphs for other outcome variables are available upon request.

[12] Even though panel (b) of Fig. 1 presents a difference in income between the treated and fishery control groups in 1997, that difference is not statistically significant.

[13] These percentage changes are calculated based on a median SST anomaly days of 77. $\%change = \exp(\beta_{2000} * 77) - 1$.

Table 2
Effects of coral bleaching on income.

Area Control	(1) log(income)	(2) Positive	Fishery Control	(3) log(income)	(4) Positive
A: Binary treatment			*A: Binary treatment*		
I(2000) * Fish	−0.3236	0.0034	I(2000) * Fish	−0.6213	−0.0068
	(0.1351)	(0.0471)		(0.2226)	(0.0502)
I(2007) * Fish	−0.0012	−0.0165	I(2007) * Fish	−0.0616	−0.0071
	(0.1585)	(0.0469)		(0.3026)	(0.0485)
F-Test p-value	0.0137	0.2735	F-Test p-value	0.0130	0.9830
B: SST anomaly days			*B: SST anomaly days*		
I(2000) * SSTdays	−0.0046	−0.0005	I(2000) * SSTdays	−0.0062	−0.0004
	(0.0019)	(0.0001)		(0.0032)	(0.0007)
I(2007) * SSTdays	0.0001	−0.0006	I(2007) * SSTdays	0.0008	−0.0004
	(0.0022)	(0.0003)		(0.005)	(0.0006)
F-Test p-value	0.0006	0.5637	F-Test p-value	0.0301	0.9397
N	7722	9544	N	736	881
Cluster N	19	20	Cluster N	16	16
Mean dep var	13.776	0.906	Mean dep var	13.684	0.932

Remarks: Panel A contains selected coefficients from equation (1), and panel B contains selected coefficients from equation (2). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include as control covariates the gender, age, and education of household heads. Wave, province, and household fixed effects are included in all specifications. Dependent variables are log of real household income per worker, and a dummy indicator for positive household income.

Table 3
Effects of coral bleaching on labor market outcomes—geographic control group.

	(1) Migration	(2) Work hours	(3) Work weeks	(4) Second jobs	(5) Fishermen
A: Binary treatment					
I(2000) * Fish	0.1121	1.1372	3.8924	−0.1205	−0.0807
	(0.0459)	(2.1414)	(1.7713)	(0.0541)	(0.0626)
I(2007) * Fish	−0.0584	5.7516	13.7718	0.1865	−0.3874
	(0.0787)	(2.9811)	(6.6504)	(0.1215)	(0.0275)
F-Test p-value	0.0801	0.3428	0.1682	0.0448	0.0000
B: SST anomaly days					
I(2000) * SSTdays	0.0007	−0.0141	0.0317	−0.0023	−0.0018
	(0.0003)	(0.0176)	(0.0368)	(0.0009)	(0.0009)
I(2007) * SSTdays	0.0005	0.0786	0.2317	0.0028	−0.0056
	(0.0012)	(0.0287)	(0.0549)	(0.0013)	(0.0001)
F-Test p-value	0.8068	0.0009	0.0000	0.0000	0.0003
N	7407	9530	9558	9572	9135
Cluster N	19	20	20	20	20
Mean dependent variable	0.213	31.340	35.502	0.343	0.039

Remarks: Panel A contains selected coefficients from equation (1), and panel B contains selected coefficients from equation (2). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include as control covariates the gender, age, and education of household heads. Wave, province, and household fixed effects are included in all specifications. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery.

2007. These results indicate that the income shock is mitigated over time.

Since the dependent variable of interest is log of income, households with negative or zero income are dropped from the regressions. These households account for 9.4% of the geographical sample, and 6.8% of the fishery sample. To ensure that this exclusion is not systematically different between the treatment and control groups, I estimate equations (1) and (2) with a dummy indicator for positive income as a dependent variable. The treatment coefficients in these models are not statistically significant, except under the geographical control and SST days specification.

5.2. Labor market outcomes

The income shock discussed in subsection 5.1 resulted from a shock to a natural resource, one factor of fishery production. Because other factors also contribute to fishery production and household income, we can investigate several mechanisms through which households mitigate this income shock. In particular, households could adjust their labor supplies, migrate, or switch to other industries.

Table 3 illustrates the effects of coral bleaching on labor-related outcomes using the geographic control group. The affected households are more likely to migrate 2 years after the shock rather than 9 years

Table 4
Effects of coral bleaching on consumption—geographic control group.

	(1) Non-food	(2) Total food	(3) All protein	(4) Fish	(5) Fruit/veg	(6) Grains
A: Binary treatment						
I(2000) * Fish	0.0448	−0.0457	−0.7863	−0.4417	−0.0264	−0.0503
	(0.0941)	(0.0638)	(0.2853)	(0.2888)	(0.3177)	(0.1456)
I(2007) * Fish	0.8793	0.2354	−0.4612	−0.7086	0.6553	0.5427
	(0.1935)	(0.0863)	(0.1855)	(0.3021)	(0.2014)	(0.1091)
F-Test p-value	0.0040	0.0654	0.1643	0.2635	0.0381	0.0020
B: SST anomaly days						
I(2000) * Fish	0.0019	−0.0014	−0.0106	−0.0086	−0.0013	−0.0022
	(0.0011)	(0.0007)	(0.0028)	(0.0028)	(0.0017)	(0.0015)
I(2007) * Fish	0.0092	0.0029	−0.0089	−0.0127	0.0041	0.0048
	(0.0018)	(0.0012)	(0.0021)	(0.0017)	(0.0017)	(0.0029)
F-Test p-value	0.0002	0.0005	0.4756	0.2373	0.0322	0.0069
N	9464	9544	9544	9544	9544	9544
Cluster N	20	20	20	20	20	20
Mean dep var	10.675	8.863	6.918	4.768	6.071	6.661

Remarks: Panel A contains selected coefficients from equation (1), and panel B contains selected coefficients from equation (2). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include as control covariates the gender, age, and education of household heads. Wave, province, and household fixed effects are included in all specifications. All consumption measures are log of real consumption expenditures per household member.

after,[14] in line with a theoretical result from the exogenous price scenario (see Appendix A for details). Using the binary treatment and the geographical control specification, the affected households were 11.2 percentage points more likely to migrate than the control group in 2000, but the coefficient for 2007 is not statistically significant. Earlier migration allows households to enjoy higher wages sooner. If the cost of migration is constant over time, then sooner migration has a greater payoff than later migration.

This finding is robust to many alternative specifications (Tables D.1 and C.2). However, when the binary treatment is instrumented with SST anomaly days, the timing of migration flips—migration only happened in 2007, not 2000 (Table C.4).[15] This might stem from possible endogeneity in the reporting of coral bleaching—coral bleaching in remote areas is less likely to be reported, and migration out of these areas is also more costly. For this reason, OLS might overestimate the effect on migration in the short run when the costs of migration might be more substantial.

One caveat of the results on migration is that the average treatment effect does not account for general equilibrium effects. For example, the treated group's migration to a new area might lead to an increase in competition in that area. This situation can cause local residents, who potentially are in the control group, to migrate. A spillover test comparing fishery and nonfishery households in the control area indicates that this hypothesis is not true. The coefficient on $I(2000) * Fish$ is not statistically significant with the p-value around 0.42.[16]

Almost a decade after the shock, the affected households were able to find more adjustment channels. I observe that the affected households were more likely to increase their labor supply and switch to other industries in 2007 than in 2000. In particular, coefficients on working hours per week are positive and statistically significant only in 2007, and the magnitudes of these effects are large. Under the binary treatment and geographic control group specification, the estimated relative increase in working hours is 5.8 h per week, and the relative increase in working weeks is 13.8 weeks per year in 2007. Even though the treated households also increased their working weeks in 2000 under the binary treatment specification, the magnitude of this effect is small relative to the effect in 2007. In addition, I find that the affected households were less likely to work second jobs in 2000 but were more likely to do so relative to the control groups in 2007. Finally, compared with other households in the same area, the affected fishery households are less likely to remain in fishery in the long run. Similar results can be obtained using the fishery control group, albeit to a somewhat weaker extent because of a smaller sample size. These results are presented in Table D.1 in Appendix D.

Taken together, these findings have two important implications. First, they suggest that a decrease in a fish stock resource cannot be easily substituted in the short run with an increase in labor input. The affected households did not significantly increase their labor supply in 2000 possibly because the fish stock resource at that time was so poor that an increase in labor input may not have improved the marginal product.

Second, the marine resource in Indonesia might have recovered after coral bleaching, but the recovery process happened rather slowly. The presence of income shock in 2000 and the finding that almost no other labor activities changed during that time imply that the resource condition was poor two years after coral bleaching. Marine resource recovery may have caused the increase in labor supply and second jobs in 2007. However, the result that households were less likely to stay in fishery in the long run somewhat weakens this argument.

Another reasonable explanation is that the treated households might not be able to work outside of fishery in the short run because of a lack of skills or labor market frictions. This effect is alleviated over time, as people acquire new skills and the market frictions diminish.

5.3. Consumption

The regression results in Table 4 and Table D.2 generally indicate that consumption expenditures, overall, do not decrease with income but increases with it. The exception to this pattern is protein consumption expenditures, which declined in both periods. Consumption measures explored here include nonfood consumption expenditure during the previous 12 months and detailed food consump-

[14] Migration is coded as a flow variable; thus, this result implies that households did not migrate back in 2007.

[15] This flip is also similar to the finding using SST days treatment and the fishery control in Table D.1.

[16] Complete spillover results are available upon request.

tion expenditures during the previous week. The nonfood consumption measure consists of expenditures on clothing, household supplies, medical costs, and others. Most consumption measures did not statistically change in 2000 but increased in 2007 as income improved.

The treatment coefficient for log protein consumption expenditure in 2000 is negative, large in magnitude, and statistically significant across all model specifications. The 2007 coefficients for protein are all negative but smaller in magnitude than the 2000 coefficients. For example, under the geographic control group specification (Table 4), the binary treatment coefficient in 2000 is −0.7863, and the 2007 coefficient is −0.4612.

Because all consumption measures are log of consumption expenditures, the decrease in consumption could have resulted from a decrease in price and/or a decrease in quantity. The theoretical framework suggests that the quantity of fish consumed declines in both the short and log runs regardless of whether fish prices are endogenous or exogenous. On the empirical side, the geographical control group specification controls for the price effect as people in the same geographical area should have incurred similar prices. Therefore, the estimates from these specifications can be interpreted as the quantity effect. Additionally, because coral bleaching was associated with a fish supply shock, the price of fish should have increased in coral bleaching areas, as suggested by the theoretical model. This implies that the estimates on protein consumption expenditures under the fishery control group specifications in Table D.2 would be the lower bound for the quantity effect.

The fall in protein consumption is particularly problematic when the affected households were in fishery, and their protein source was closely tied with their income source. These households were constrained by both a decline in income and a fall in fish stock. Empirical results suggest that both channels might contribute to the large decline in protein consumption.

First, if protein is a normal/luxury goods for households, protein consumption will decline as income decreases. All the empirical results so far imply that protein is a luxury good.[17] Estimates for the percentage decline in protein consumption expenditure in 2000 are greater than the comparable estimates for the income shock. As a result, a back-of-the-envelope calculation yields an income elasticity of protein consumption expenditure greater than one. For example, under the geographic control group and binary treatment specification, the coefficient on $I(2000) * Fish$ in the log income model is −0.3236 (Table 2), which is equal to a decline in income of 27.65%. The coefficient on $I(2000) * Fish$ in the log protein consumption expenditure model is −0.7863 (see Table 4), or a 54.45% decrease in protein consumption expenditure. Thus, the income elasticity of protein consumption expenditure is equal to 1.97, indicating that protein consumption is a luxury good.

To precisely test whether protein is a normal/luxury good, I distinguish between consumption produced within the household and that purchased from the outside.[18] Columns 4–5 in the upper panel of Table D.4 contain results on meat and other protein (eggs, dairy, and plant protein) purchases. Although meat purchase did not statistically change, the coefficient on $I(2000) * Fish$ in the other protein model is very large in magnitude at −1.2321. This coefficient implies an income elasticity of 2.56, indicating that eggs, dairy, and plant protein are luxury goods.

The finding that protein is a normal/luxury good suggests that economic development might lead to a significant improvement in nutrition and health outcomes. Moreover, cash transfer might be an effective policy to mitigate decreased protein consumption.

The second channel through which coral bleaching could affect protein consumption is the availability of fish. The treated group's consumption of their own catch allows us to examine if fish become less available after coral bleaching. Column 3 in the bottom panel of Table D.4 illustrates the effects of coral bleaching on fishing households' consumption of their own catch. These results suggest that consumption of their own catch declined in 2000 and 2007. As the affected households were still active in fishery and did not change their labor supply in 2000, these findings imply that the fish stock declined and protein from fish became less available—at least in 2000. The decrease in consumption of their own catch could have resulted from a substitution of household consumption for sales, but this substitution was incomplete because the total fish consumption and household income decreased. The implications from the 2007 result are less clear, because by that time, the affected households might have left fishery.

The next question to ask is whether nonfishery households in coral bleaching areas were affected by this fish supply shock. By comparing nonfishery households in coral bleaching areas to those outside, the results do not show a clear evidence for a spillover of fish supply shock (Table D.6). Nonfishery households' fish consumption did not statistically change in the coral bleaching areas relative to the control area. However, the fact that fish consumption expenditure does not change could have stemmed from an increase in price combined with a fall in consumption quantity. Markets might have allocated fish to coral bleaching areas; thus, coral bleaching did not affect fish available for purchase.

These empirical results are robust to alternative specifications, including triple differences and instrumental variable. A placebo treatment test comparing fishery households to other households in unaffected areas also indicates almost no statistically significant differences between these households. These robustness checks are included in Appendix C.

6. Conclusion

In this paper I examine relationships among a long-lasting income shock and several adjustment mechanisms. The source of the exogenous income shock is coral bleaching, which occurs because of abnormally high sea surface temperatures. Using the IFLS, I empirically show that fishery households affected by coral bleaching had lower income compared with other households two years after the bleaching occurred. This income shock was mitigated over time as these households adapted. The adjustment channels considered in this paper include labor activities and consumption.

The results from this paper have interesting policy implications from development and environmental perspectives. From the development angle, these findings provide insights into methods to alleviate the impacts of unexpected, long-lasting income shocks. From the environmental perspective, this paper illuminates how climate change affects people, especially those in vulnerable coastal communities.

Some evidence suggests that the affected households respond to the income shock in the short run by migrating, whereas other evidence indicates that migration occurs only in the long run. This result suggests that policies that facilitate migration might be useful. For example, in the case of fishery households that faced a decline in fish stock, a policy that directs them to an area with a healthy fish stock may be useful. Nonetheless, there could be several problems with migration. For example, migrants might face resistance from local residents when trying to tap into new resources or the cost of adapting to a new area could be very high. More broadly, migration may not be feasible for all households. For instance, agricultural households that own or rely on land face a high cost of migration and may be better off not migrating. Additionally, if a shock is widespread, the cost of migration will increase as households must

[17] An income elasticity of demand for a luxury good is greater than one.

[18] These two types of consumption might not be perfect substitutes if markets are imperfect, for example when transaction costs exist.

migrate farther. Subsidizing migration in these situations could make migration more feasible, but the cost of the subsidy could be very high.

I also observe that the affected households increased their labor supply, took second jobs, and switched to another industry in the long run but not in the short run. Consequently, skill acquisition policy might help mitigate these types of income shocks. If these households had acquired new skills earlier, they may have been able to work in other industries sooner, and the income shock could have been less severe in the short run. In addition, labor market frictions might have prevented the affected households from supplying labor to other industries in the short run. In this case, policies that reduce such frictions, like those aimed to reduce search costs and facilitate information flow, could be useful.

In terms of consumption, I find evidence for a large decline in protein consumption, which could be persistent in the long run. The evidence also suggests that protein from fish became less available after coral bleaching and that protein was a luxury good. These results imply that policies such as consumption subsidy and nutrition supplements that help smooth consumption would be useful. In particular, knowing that protein is a luxury good implies that cash transfers might be very effective.

A. Theoretical Framework– Further Details

This appendix contains the details of the main theoretical framework and discusses its alternative specifications. The main theoretical framework discussed in the paper is given by

$$\max_{FC_t, C_t, LF_t, LW_t, M_t} \alpha \log FC_1 + (1-\alpha)\log C_1 + \phi(\alpha \log FC_2 + (1-\alpha)\log C_2)$$

$$\text{s.t. } p_1 FC_1 + p_1 FC_2 + C_1 + p_{c2} C_2 \le p_1 \theta LF_1^{\beta} + p_2 \theta LF_2^{\beta} + w_1 LW_1 + w_2 LW_2 - m_1 M_1 - m_2 M_2$$

$$w_1 = \eta \log M_1$$

$$w_2 = \eta \log M_1 \log M_2$$

$$\tau = LW_t + LF_t; t = 1, 2$$

where FC_t denotes fish consumed, C_t denotes non-fish consumption, LF_t denotes labor input in fishery, LW_t denotes labor supply outside of fishery, and M_t denotes migration distance in period t. The household maximizes utility which is a log linear function of fish consumption, FC_t, and other consumption, C_t, subject to a budget constraint. The household may engage in a fishery, and fishery outputs are functions of the initial fish resource endowment, θ, and fishery labor input, LF_t. The household may also supply labor in other industries, LW_t, and earn labor income which is a function of migration, M_t.

I assume that fish prices can be either exogenous or endogenous. In the former case, the fish price in the first period is exogenous, and it grows at the same rate as other prices in the model in the second period. In the latter, the market for fish is assumed to be perfectly competitive, and prices can adjust freely to clear the market in each time period.

Figs. A.1 and A.2 outline comparative statics with respect to θ under exogenous and endogenous fish price scenarios, respectively. In addition to the findings explained in Section 3, it is worth noting that under the exogenous price scenario,[19] the household does not supply labor in fishery in the second period. This is consistent with the empirical finding that the household is less likely to be in fisheries in the long run.

[19] The fish price in the first period is assumed to be at a level similar to the one in the endogenous price scenario, and this price increases by 5%, the same rate as other prices in the model, in the second period. All parameters are the same under both scenarios.

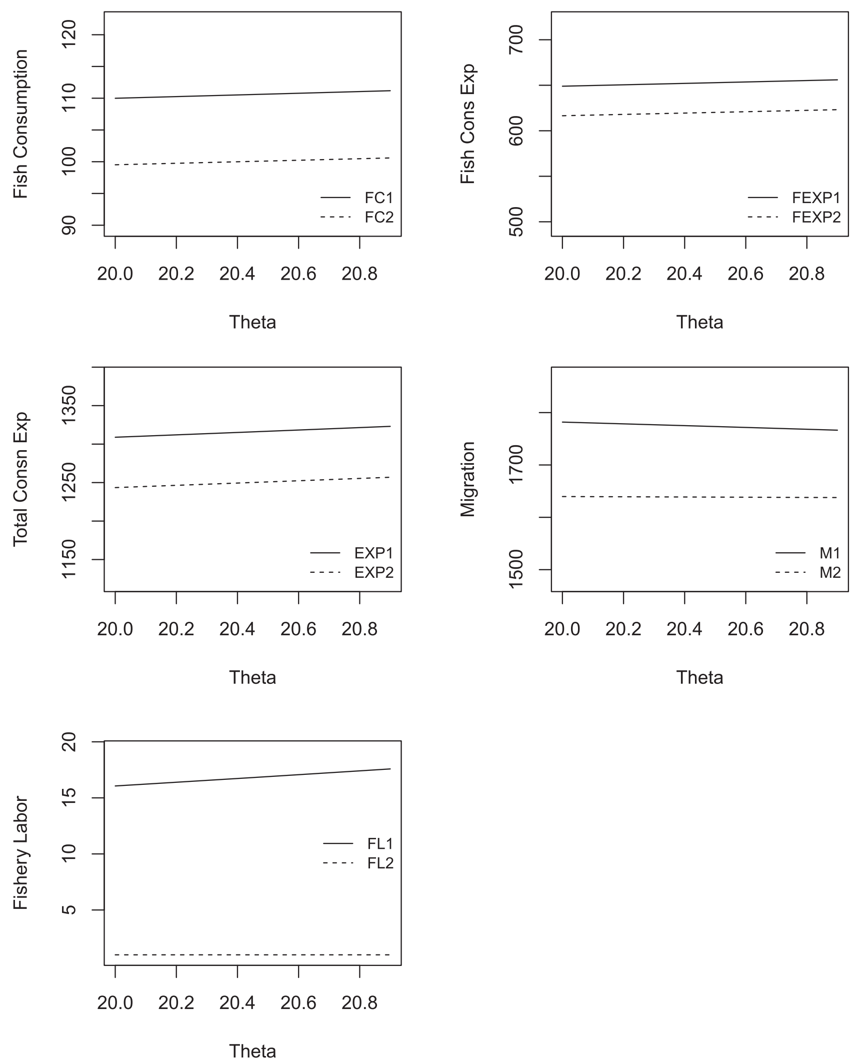


Figure generated by author based on numerical optimization of the theoretical model assuming that $\alpha = \beta = 0.5$, $p_1 = 6$, $p_2 = 6.3$, $p_{2c} = 1.05$, $\eta = 2$, $m_1 = .2$, $m_2 = .21$, $\phi = .95$, and $\tau = 24$.

Fig. A.1 Theoretical relationships between the initial fish resource (θ), consumption expenditures, migration, and fishery labor input—Exogenous prices.

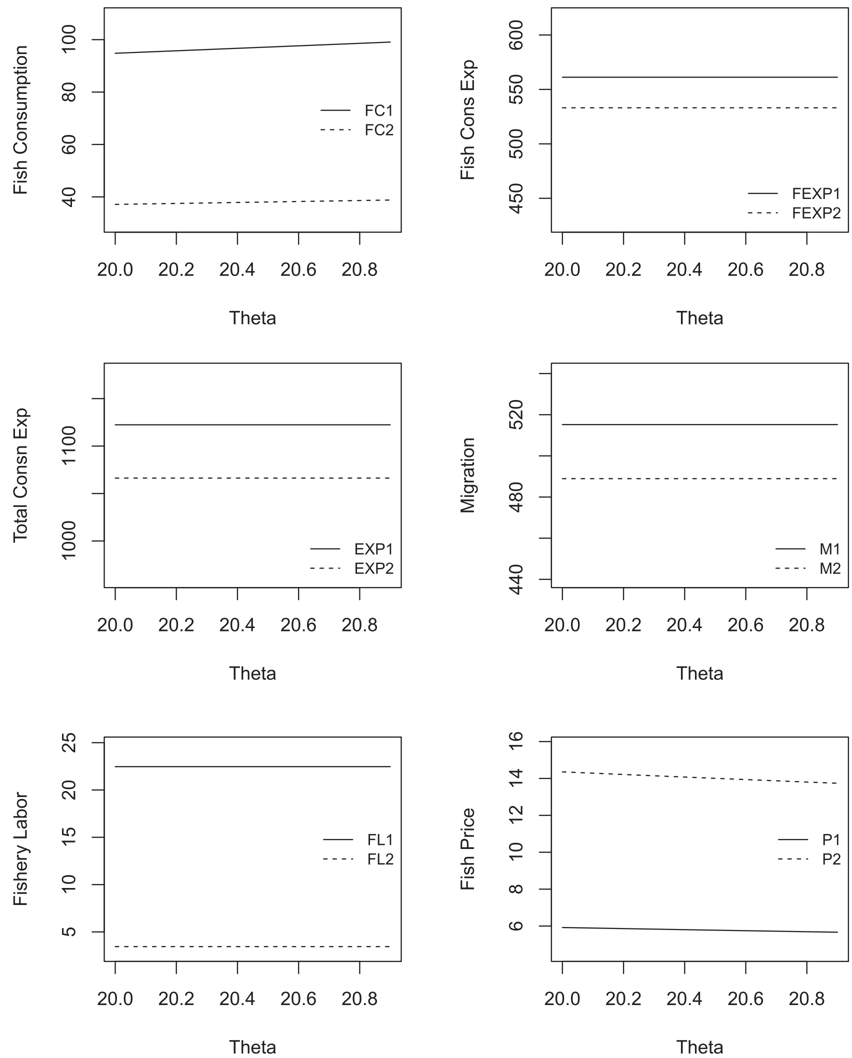


Figure generated by author based on numerical optimization of the theoretical model assuming that $\alpha = \beta = 0.5$, $p_{2c} = 1.05$, $\eta = 2$, $m_1 = .2$, $m_2 = .21$, $\phi = .95$, and $\tau = 24$.

Fig. A.2 Theoretical relationships between the initial fish resource (θ), consumption expenditures, migration, fishery labor input, and fish prices—Endogenous prices.

B. Data details

This appendix contains a map of the treated and control areas (Fig. B.1), summary statistics of key variables (Table B.1), and empirical distributions of SST anomaly days for the treated group and fishery control (Fig. B.2).

Figure generated by author based on the IFLS province coverage and reported coral bleaching spots from Goreau et al. (2000)

Fig. B.1 IFLS provinces and treated area.

Table B.1
Summary statistics by treatment status, 1997 wave.

	Treated group			Geographic control				Fishery control			
	Mean	SD	N	Mean	SD	N	p-value	Mean	SD	N	p-value
HH head's age	43.25	12.27	72	48.98	33.74	1948	0.1511	43.91	11.91	112	0.7171
Male HH head	0.972	0.165	72	0.805	0.396	1948	0.0004	0.929	0.259	112	0.2045
Number of members in fishery	1.184	0.647	76	0.000	0.000	2115	1.0000	1.183	0.580	120	0.9921
Fraction of labor in fishery	0.421	0.212	76	0.000	0.000	2115	1.0000	0.431	0.185	120	0.7226
SST anomaly days	58.39	32.90	76	0.00	0.00	2115	1.0000	8.66	20.45	120	0.0000
Real HH income	1,413,430	2,124,524	73	1,884,484	7,467,620	1777	0.5907	2,847,497	7,248,134	112	0.1020
Second job	0.382	0.489	76	0.294	0.456	2115	0.1011	0.167	0.374	120	0.0006
Fraction of female labor	0.201	0.201	76	0.273	0.292	2115	0.0325	0.112	0.184	120	0.0018
Working weeks per year	38.63	20.09	76	32.85	21.16	2110	0.0192	27.76	12.19	120	0.0000
Working hours per week	33.22	17.54	76	27.62	18.85	2112	0.0107	27.97	15.95	120	0.0320
Total food consumption expdt	6128	4134	76	8324	17,927	2110	0.2862	8116	7169	120	0.0293
Protein consumption expdt	1444	1457	76	2096	5815	2110	0.3288	1828	1831	120	0.1238
Nonfood consumption expdt	39,347	60,296	76	102,742	257,106	2052	0.0319	71,509	118,671	116	0.0302

Remarks: p-values from unpaired t-tests for differences in means between the treated group and each control group.

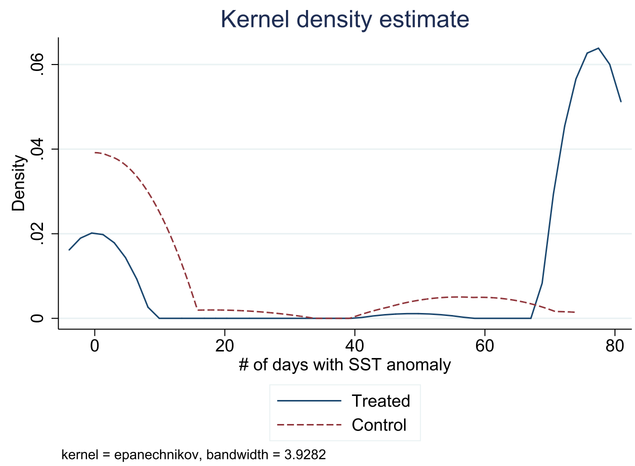


Figure generated by author

Fig. B.2 Distribution of SST anomaly days among fishery households.

C. Robustness Checks

This appendix examines robustness of empirical results using a triple difference specification, an instrumental variable approach, and a placebo treatment test. Firstly, the triple difference specification controls for a broader range of confounding factors than the double difference model. Specifically, the treatment effects are identified even when there are both time-varying unobservables that affect all fishery households and those that affect every household in the coral bleaching areas. By contrast, the double difference specification allows for only one type of unobservables at a time. For instance, under the double difference when the regression sample is those in coral bleaching areas, the treatment effect will not be identified if there is a country-wide change in fishing regulations. The new regulations are likely to affect only the treated group and not the control group. Identification should then be based on the fishery control group. If there also exists a location-specific shock that makes the trend of outcome among the treated fishery households different from that of the control fishery households, then the fishery control group will not be valid either. In this case, the treatment effect can still be identified by using the triple difference approach, provided that the location-specific unobservable similarly affects all households in the area.

I utilize the triple difference estimator and demonstrate that the results are broadly consistent with the main specifications. The estimating equation based on the triple difference specification can be written as

$$Y_{ht} = \alpha + \delta_p Post_t + \delta_f Fish_h + \delta_b Bleach_h + \phi_1 Post_t * Fish_h + \phi_2 Post_t * Bleach_h + \phi_3 Fish_h * Bleach_h + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * Fish_h * Bleach_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}. \tag{C.1}$$

Identification based on a triple difference specification, nonetheless, comes at a cost of power. This is a particular concern when the treatment group is small, as is the case here. Table C.1 presents the results from the triple difference model on income. The estimates still exhibit similar patterns as those from the main results. However, some coefficients cannot be precisely estimated. Even though the triple difference estimate for 2000 in the income model is not statistically significant under traditional significance levels, it is negative and large in absolute value compared to the 2007 estimate. Specifically, the 2000 coefficient is estimated to be −0.2803 with a p-value of.218 and a 95% confidence interval that is mostly in the negative range, (−0.74, 0.18). The 2007 coefficient is estimated to be −0.0315 with a p-value of 0.899, in line with the adaptations suggested by the difference-in-differences specifications.

Table C.1
Effects of coral bleaching on income - triple differences.

	(1) log(income)	(2) Positive income
I(2000) ∗ Fish ∗ Bleach	−0.2803	0.0393
	(0.2194)	(0.0595)
I(2007) ∗ Fish ∗ Bleach	−0.0315	0.0265
	(0.2418)	(0.055)
F-Test p-value	0.0395	0.4356
N	25,148	31,244
Cluster N	19	20
Mean dependent variable	13.875	0.100

Remarks: Estimates based on (C.1). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Dependent variables are a dummy indicator for positive household income and log of real household income per worker.

Results on labor market outcomes and consumption based on the triple difference model also demonstrate similar findings as the main results, despite some weaker estimates. The 2000 coefficient on migration is highly significant and large. Results on labor supply, secondary jobs, and industry switching are also similar to the main results.

Table C.2
Effects of coral bleaching on labor market outcomes - triple differences.

	(1) Migration	(2) Work hours	(3) Work weeks	(4) Second job	(5) Fishermen
I(2000) ∗ Fish ∗ Bleach	0.247	0.3732	2.1667	−0.1694	0.0139
	(0.12)	(3.822)	(2.1511)	(0.0808)	(0.0909)
I(2007) ∗ Fish ∗ Bleach	0.0877	5.9072	13.9556	0.1786	−0.2857
	(0.1432)	(4.8109)	(8.2002)	(0.1546)	(0.0732)
F-Test p-value	0.2157	0.3421	0.1823	0.0733	0.0000
N	24,407	31,198	31,301	31,348	30,023
Cluster N	19	20	20	20	20
Mean dependent variable	0.220	30.712	33.457	0.296	0.036

Remarks: Estimates based on (C.1). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery.

In terms of consumption, the triple difference specifications also confirm the finding on protein consumption. The estimate for β_{2000} for total protein expenditure is the largest in absolute terms compared with other consumption. In addition, β_{2007} for protein is also negative and statistically significant. The coefficients on fish and other protein expenditures also follow a similar pattern. Most of the other consumption measures have negative treatment coefficients in 2000 but not 2007; however, these coefficients are not statistically significant.

Table C.3
Effects of coral bleaching on consumption - triple differences.

	(1) Total food	(2) Protein	(3) Fish	(4) Meat	(5) Oth protein	(6) Fruit/veg	(7) Grains
I(2000) ∗ Bleach ∗ Fish	−0.1118	−0.7961	−0.7455	0.1343	−1.1021	−0.1492	0.2109
	(0.1259)	(0.3415)	(0.3938)	(0.5615)	(0.3124)	(0.4361)	(0.2411)
I(2007) ∗ Bleach ∗ Fish	0.1789	−0.5407	−0.9589	0.7924	−0.1303	0.5693	0.7188
	(0.1298)	(0.2585)	(0.3796)	(0.8059)	(0.3184)	(0.4896)	(0.2113)
F-Test p-value	0.0818	0.2589	0.3702	0.1519	0.0013	0.0202	0.0034
Mean dep var	8.8786	6.8447	4.6711	2.7228	5.4818	6.0596	6.5347
N	31,244	31,244	31,244	31,244	31,244	31,244	31,244
Cluster N	20	20	20	20	20	20	20

Remarks: Estimates based on (C.1). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all specifications. All consumption measures are log of real consumption expenditures per household member.

The second robustness check is to use the instrumental variable framework to estimate the treatment effects. I instrument the binary treatment variable with SST anomaly days because the SST anomaly days is used for coral bleaching prediction. Table C.4 exhibits the IV results and demonstrates that the key findings also hold under this specification. Notably, most of the treatment coefficients are larger in magnitude in the IV models, compared with the similar coefficients under the OLS binary treatment models.

Table C.4
Robustness check - IV estimation.

	Income	Labor activities					Consumption			
	(1) Income	(2) Migration	(3) Work hours	(4) Work weeks	(5) Second job	(6) Fishermen	(7) Non-food	(8) Total food	(9) Protein	(10) Food staples
I(2000) ∗ Bleach	−0.6563	0.1028	−3.5353	−2.2027	−0.2492	−0.1569	0.0309	−0.1707	−0.9241	0.3812
	(0.274)	(0.0718)	(5.0198)	(5.2063)	(0.1212)	(0.1879)	(0.3648)	(0.138)	(0.4762)	(0.4383)
I(2007) ∗ Bleach	0.1428	0.3875	7.9569	21.4692	0.2512	−0.13	0.8907	0.293	−0.8296	0.3865
	(0.2974)	(0.1008)	(4.5859)	(5.6216)	(0.1156)	(0.1895)	(0.4326)	(0.1538)	(0.4678)	(0.3752)
F-Test p-value	0.0061	0.0048	0.0260	0.0001	0.0002	0.8986	0.0400	0.0130	0.8473	0.9911
N	736	673	882	882	883	829	875	881	881	881
Mean dependent variable	13.6844	0.1768	29.6818	32.9261	0.3126	0.8118	10.376	8.8305	6.8266	6.9139

Remarks: Household clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. Sample is all fishery households. The binary treatment variables are instrumented with SST anomaly days variables. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Income is log of real household income per worker. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery. All consumption measures are log of real consumption expenditure per household member.

The third robustness check is for placebo treatment effects. In particular, among households that lived outside of coral bleaching areas, fishery and nonfishery households should not exhibit differences in outcomes post-treatment. Table C.5 illustrates the results from the models where the sample is all households that lived in control areas. These results indicate that fishery and nonfishery households were mostly similar in terms of labor market outcomes and consumption in the absence of coral bleaching.[20] This provides reassurance that the treatment effects presented earlier were not driven by unobservables inherent in the fishery sector.

Table C.5
Robustness check - false treatment on the control area.

	Income		Labor activities					Consumption			
	(1) Positive income	(2) Income	(3) Migration	(4) Work hours	(5) Work weeks	(6) Second job	(7) Fishermen	(8) Non-food	(9) Total food	(10) Protein	(11) Grains
I(2000) ∗ Fish	0.0347	0.1548	−0.0623	0.7491	1.1199	0.0221	−0.0155	0.1762	0.0926	0.0966	−0.4051
	(0.0364)	(0.1592)	(0.0752)	(3.5556)	(1.8346)	(0.0628)	(0.099)	(0.2413)	(0.1033)	(0.1931)	(0.235)
I(2007) ∗ Fish	0.0467	−0.1912	−0.2053	−0.8808	−0.8393	0.0177	−0.2015**	−0.1032	0.012	−0.0814	−0.0871
	(0.0377)	(0.21)	(0.1602)	(3.8574)	(2.3955)	(0.0528)	(0.0904)	(0.3101)	(0.0968)	(0.1662)	(0.1815)
F-Test p-value	0.1686	0.0961	0.2139	0.6457	0.4802	0.9360	0.1349	0.0862	0.2181	0.2105	0.1240
N	21,700	17,426	17,000	21,668	21,743	21,776	20,888	21,308	21,700	21,700	21,700
Mean dep var	0.897	13.918	0.223	30.436	32.559	0.275	0.034	10.708	8.886	6.812	6.479
N Cluster	18	18	18	18	18	18	18	18	18	18	18

Remarks: Estimates based on (1). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. Sample is all households in areas without coral bleaching. Wave, province, and household fixed effects are included in all the specifications. The dependent variable in Column (1) is whether a household has positive income. Income is log of real household income per worker. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery. All consumption measures are log of real consumption expenditure per household member.

D. Additional Empirical Results

Table D.1 exhibits effects of coral bleaching on labor outcomes using the fishery control group. Most results are similar to the results presented in the main empirical section. Table D.2 illustrates the effects of coral bleaching on consumption using the fishery control group.

Table D.1
Effects of coral bleaching on labor market outcomes - fishery control group.

	(1) Migration	(2) Work hours	(3) Work weeks	(4) Second jobs	(5) Fishermen
A: Binary treatment					
I(2000) ∗ Fish	0.1596	−1.253	−0.9271	−0.1752	−0.0465
	(0.0949)	(5.0417)	(3.4887)	(0.1127)	(0.1238)
I(2007) ∗ Fish	0.0861	6.7686	14.5637	0.2161	−0.1595
	(0.1505)	(4.346)	(5.3539)	(0.1059)	(0.1025)
F-Test p-value	0.4262	0.1022	0.0246	0.0124	0.3854
B: SST anomaly days					
I(2000) ∗ SSTdays	0.0012	−0.025	−0.0033	−0.002	−0.0013
	(0.0013)	(0.0624)	(0.0399)	(0.0013)	(0.0018)
I(2007) ∗ SSTdays	0.0037	0.0741	0.2027	0.0023	−0.0011
	(0.0019)	(0.0682)	(0.0575)	(0.0012)	(0.0021)
F-Test p-value	0.0589	0.0600	0.0002	0.0007	0.9144
N	673	882	882	883	829
Cluster N	16	16	16	16	15
Mean dependent variable	0.177	29.682	32.926	0.313	0.812

Remarks: Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery.

Table D.2
Effects of coral bleaching on consumption - fishery control group.

	(1) Non-food	(2) Total food	(3) Protein	(4) Fish	(5) Fruit/veg	(6) Grains
A: Binary treatment						
I(2000) ∗ Fish	−0.223	−0.1208	−0.7694	−0.737	−0.0426	0.4421
	(0.3281)	(0.1511)	(0.4028)	(0.4161)	(0.5414)	(0.2901)
I(2007) ∗ Fish	1.0509	0.2751	−0.3621	−0.7118	0.8165	0.5933
	(0.3729)	(0.1184)	(0.2544)	(0.3949)	(0.4772)	(0.2242)
F-Test p-value	0.0002	0.0241	0.2229	0.9401	0.0127	0.4472

(*continued on next page*)

[20] The exception is the 2007 coefficient the number of fishermen that is negative and statistically significant. This fact that helps explain why the treatment effect on fishery using the fishery control group is relatively weak, despite the strong effect using the geographic control group and triple difference specifications.

Table D.2 *(continued)*

	(1) Non-food	(2) Total food	(3) Protein	(4) Fish	(5) Fruit/veg	(6) Grains
B: SST anomaly days						
I(2000) ∗ SST	0.0016	−0.0014	−0.0097	−0.0136	−0.0029	0.0041
	(0.0041)	(0.0015)	(0.0037)	(0.0038)	(0.0053)	(0.0029)
I(2007) ∗ SST	0.009	0.0026	−0.009	−0.0132	0.0025	0.0042
	(0.0058)	(0.0015)	(0.0026)	(0.0052)	(0.0038)	(0.0035)
F-Test p-value	0.1103	0.0289	0.8520	0.9417	0.2075	0.9708
N	875	881	881	881	881	881
Cluster N	16	16	16	16	16	16
Mean dependent variable	10.376	8.831	6.827	5.768	5.882	6.914

Remarks: Panel A contains selected coefficients from equation (1), and panel B contains selected coefficients from equation (2). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all specifications. All consumption measures are log of real consumption expenditure per household member.

Tables D.3 and D.4 show the results on purchased and produced consumption using the double difference specification. Table D.5 exhibits the results using the triple difference specification.

Table D.3
Effects of coral bleaching on consumption purchases and consumption of household production - fishery control

	Household purchase						
	(1) Total food	(2) Protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grains
A: Binary treatment							
I(2000) ∗ Fish	−0.1024	−0.97	0.3409	0.8615	−1.803	−0.3873	0.3846
	(0.1911)	(0.7233)	(0.5724)	(0.3409)	(0.6467)	(0.5946)	(0.5974)
I(2007) ∗ Fish	0.4533	−0.0385	0.6508	0.5726	−0.172	0.3665	1.0582
	(0.191)	(0.5097)	(0.8657)	(0.8028)	(0.681)	(0.6203)	(0.5747)
F-Test p-value	0.0042	0.1210	0.7184	0.7144	0.0015	0.0730	0.3929
B: SST anomaly days							
I(2000) ∗ SST	−0.0014	−0.0113	0.0025	0.0126	−0.0143	−0.0084	0.0007
	(0.0022)	(0.0066)	(0.007)	(0.0054)	(0.0108)	(0.0047)	(0.0058)
I(2007) ∗ SST	0.0035	−0.0081	−0.0046	0.0083	−0.0085	−0.0064	0.0037
	(0.0021)	(0.0059)	(0.0126)	(0.007)	(0.009)	(0.0061)	(0.0108)
F-Test p-value	0.0124	0.4622	0.4286	0.4379	0.3744	0.7447	0.8244
N	881	881	881	881	881	881	881
Cluster N	16	16	16	16	16	16	16
Mean dep var	8.583	5.657	2.615	0.677	4.431	5.355	6.137
	Household production						
	(1) Total food	(2) Protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grains
A: Binary treatment							
I(2000) ∗ Fish	−0.511	−1.5876	−1.4681	−0.6513	0.2174	0.0546	0.9808
	(0.5636)	(0.6602)	(0.8172)	(0.1827)	(0.2647)	(0.8578)	(1.0642)
I(2007) ∗ Fish	0.0443	−0.7983	−1.1436	0.2603	0.6753	0.581	0.6954
	(0.4558)	(0.7598)	(0.8138)	(0.3433)	(0.3104)	(0.4459)	(0.7315)
F-Test p-value	0.4363	0.0992	0.3565	0.0487	0.0924	0.3929	0.7469
B: SST anomaly days							
I(2000) ∗ SST	−0.0102	−0.0244	−0.0228	−0.0053	0.0058	0.0088	0.0194
	(0.0074)	(0.0078)	(0.0128)	(0.0024)	(0.0054)	(0.0148)	(0.011)
I(2007) ∗ SST	0.0034	−0.0117	−0.0072	−0.0003	0.0036	0.0148	0.0203
	(0.0053)	(0.0105)	(0.0116)	(0.0047)	(0.005)	(0.0069)	(0.0056)
F-Test p-value	0.0735	0.0398	0.0002	0.4475	0.7544	0.5991	0.9385
N	881	881	881	881	881	881	881
Cluster N	16	16	16	16	16	16	16
Mean dep var	4.943	3.257	2.585	−1.064	−0.453	0.661	0.855

Remarks: Panel A contains selected coefficients from equation (1), and panel B contains selected coefficients from equation (2). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table D.4
Effects of coral bleaching on consumption purchases and consumption of household production - geographical control.

	Household purchases						
	(1) Total food	(2) Protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grains
A: Binary treatment							
I(2000) ∗ Fish	−0.047	−0.6165	0.3719	0.2396	−1.2321	−0.2318	−0.2884
	(0.0836)	(0.5662)	(0.2574)	(0.2094)	(0.4673)	(0.4367)	(0.2246)
I(2007) ∗ Fish	0.2783	0.1139	0.3617	0.7864	−0.1503	−0.0397	0.7322
	(0.0628)	(0.3422)	(0.2498)	(0.6951)	(0.379)	(0.2684)	(0.1742)
F-Test p-value	0.0184	0.0581	0.9810	0.4085	0.0197	0.5733	0.0051
B: SST anomaly days							
I(2000) ∗ SSTdays	−0.0014	−0.0105	0.0078	0.0063	−0.0155	−0.0043	−0.0076
	(0.0011)	(0.0039)	(0.0032)	(0.0008)	(0.0065)	(0.0033)	(0.0035)
I(2007) ∗ SSTdays	0.0029	−0.0044	0.0024	0.0124	−0.0076	−0.0069	0.006
	(0.0013)	(0.0026)	(0.0041)	(0.0041)	(0.0025)	(0.0018)	(0.0062)
F-Test p-value	0.0007	0.1573	0.3309	0.1744	0.2391	0.2763	0.0292
N	9544	9544	9544	9544	9544	9544	9544
Cluster N	20	20	20	20	20	20	20
Mean dep var	8.598	6.588	4.293	2.110	5.008	5.188	5.138
	Household production						
	(1) Total food	(2) Protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grains
A: Binary treatment							
I(2000) ∗ Fish	−0.5651	−1.8031	−1.0444	−0.4992	−0.4178	−0.5929	0.6065
	(0.3536)	(0.5727)	(0.6459)	(0.2059)	(0.453)	(0.2832)	(0.4583)
I(2007) ∗ Fish	−0.1596	−0.8385	−0.9457	−0.0407	0.7411	0.3255	0.6939
	(0.2437)	(0.2832)	(0.4965)	(0.6238)	(0.1806)	(0.3034)	(0.4066)
F-Test p-value	0.4659	0.1463	0.7816	0.3138	0.0214	0.0010	0.8072
B: SST anomaly days							
I(2000) ∗ SST	−0.0102	−0.0312	−0.0244	−0.0051	−0.0053	−0.0111	0.0108
	(0.0044)	(0.005)	(0.0032)	(0.0012)	(0.006)	(0.0017)	(0.0041)
I(2007) ∗ SST	−0.0019	−0.0155	−0.0137	0.0009	0.0066	0.0045	0.0158
	(0.0033)	(0.0045)	(0.0035)	(0.0071)	(0.0022)	(0.0033)	(0.0013)
F-Test p-value	0.1625	0.0238	0.0000	0.3488	0.1273	0.0000	0.2339
N	9544	9544	9544	9544	9544	9544	9544
Cluster N	20	20	20	20	20	20	20
Mean dep var	4.845	1.144	−0.605	−0.593	0.125	1.938	1.900

Remarks: Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table D.5
Effects of coral bleaching on consumption purchases and consumption of household production - triple differences.

	(1) Total food	(2) Protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grains
Household Purchases							
I(2000) ∗ Bleach ∗ Fish	−0.1054	−0.8773	0.3921	0.7289	−1.3993	−0.4557	0.2385
	(0.138)	(0.5264)	(0.7075)	(0.6194)	(0.5918)	(0.4658)	(0.5925)
I(2007) ∗ Bleach ∗ Fish	0.2019	−0.2404	0.3819	0.8342	−0.2929	−0.2272	1.1701
	(0.1449)	(0.5278)	(0.777)	(0.7144)	(0.5607)	(0.5018)	(0.5465)
F-Test p-value	0.0072	0.1746	0.9885	0.8749	0.0261	0.6083	0.0762
Mean dep var	8.6520	6.5774	4.2799	2.2257	5.1998	5.3652	5.3184
Household production							
I(2000) ∗ Bleach ∗ Fish	−0.0339	−1.913	−1.5195	−0.5415	−0.2582	0.0057	0.5768
	(0.4658)	(0.6849)	(0.7391)	(0.2752)	(0.4004)	(0.5616)	(0.7942)
I(2007) ∗ Bleach ∗ Fish	0.3308	−1.0718	−1.3409	−0.1621	0.7002	0.7239	0.5382
	(0.5134)	(0.6942)	(0.6614)	(0.2667)	(0.3474)	(0.6104)	(0.7089)
F-Test p-value	0.4030	0.0074	0.4640	0.0227	0.0005	0.0021	0.8854
Mean dep var	4.088	0.643	−0.732	−0.732	−0.305	1.293	1.342
N	31,244	31,244	31,244	31,244	31,244	31,244	31,244
Cluster N	20	20	20	20	20	20	20

Remarks: Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table D.6 contains key treatment coefficients that illustrate consumption spillover within the coral bleaching areas. The specification here compares nonfishery households in coral bleaching areas with nonfishery households in the control areas.

Table D.6
Effects of coral bleaching on consumption - spillover.

	(1) Non-food	(2) Total food	(3) Protein	(4) Fish	(5) Fruit/veg	(6) Grains
A: Binary treatment						
I(2000) ∗ Bleach	−0.1	0.0559	0.099	−0.0242	0.1109	0.1271
	(0.1525)	(0.0646)	(0.1906)	(0.1189)	(0.1887)	(0.1479)
I(2007) ∗ Bleach	−0.1192	0.0804	0.0289	0.0288	0.1993	0.0168
	(0.2911)	(0.0915)	(0.1608)	(0.1444)	(0.203)	(0.1624)
F-Test p-value	0.9473	0.6407	0.3945	0.7050	0.2267	0.3165
B: SST anomaly days						
I(2000) ∗ SSTdays	0.0002	0.0006	0.0011	−0.001	0.0035	−0.0002
	(0.0013)	(0.0006)	(0.0023)	(0.0011)	(0.0028)	(0.0014)
I(2007) ∗ SSTdays	−0.0019	−0.0004	−0.0019	0.0008	0.0027	−0.0031
	(0.005)	(0.0012)	(0.0019)	(0.002)	(0.003)	(0.0012)
F-Test p-value	0.6660	0.2381	0.0065	0.2707	0.3743	0.0840
N	29,897	30,363	30,363	30,363	30,363	30,363
Cluster N	20	20	20	20	20	20
Mean dependent variable	10.707	8.880	6.845	4.639	6.065	6.524

Remarks: Panel A contains selected coefficients from equation (1), and panel B contains selected coefficients from equation (2). Province clustered standard errors are in parentheses. F-test $H_0: \beta_{2000} = \beta_{2007}$. All models include the household head's gender, age, and education as control covariates. Wave, province, and household fixed effects are included in all the specifications. Dependent variables are log of total consumption expenditures. Sample is all nonfishery households.

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